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STATIC ANALYSIS OF CABLE STAYED BRIDGE SYSTEM USING VARIOUS TYPES OF DECK PROFILES

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ABSTRACT

The Innovative deck profile of cable-stayed bridge proposed here for an analysis of different types of deck profiles by using cable stayed bridge system. The prime objective of the present work is to model an optimized Cable Stayed Bridge with economized girder with various features, i.e. span to depth ratio as constant parameter an attempt is made here to check the cost economy, structural strength of proposed by bridge by checking a ratio of load carrying capacity to material requirement respectively. The complete work consist an analysis using commercial software (MIDAS CIVIL 2016). Static analysis of bridge with variation in deck profiles, i.e., PSC-I Deck, PSC-T beam, PSC-Box girders. Parametric study will be work out using various tabular and graphical form which highlights an objective based on cost-economy aspect in terms of strength, serviceability and economy respectively are the prime criterion. Here a geometry was taken of "Pandit Dindayal Upadhyay Cable Stayed Bridge" which is presently constructing on Tapi river across Athwa to Adajan.

KEY WORDS: Cable-Stayed bridge, Single Pylon, PSC-box Deck, PSC-T Deck, PSC-I Deck Static Analysis, IRC Standard, Self Anchored Suspension type.

I. INTRODUCTION

Cable-stayed bridges are large and sophisticated structures which may greatly benefit from the use of structural optimization techniques for preliminary design improvement. Many cable-stayed bridges have been built in the last few decades because of development in: (1) materials, (2) construction techniques, and (3) computation capabilities.

The deck of cable-stayed bridge is elastically supported along the girder length by inclined stay. Therefore, the girders take not only bending moments, as in regular bridges but also significant axial forces from the inclined cables. Cable-stayed bridge girders carrying both axial forces and bending moments. The structural behavior of cable-stayed bridges is sensitive to the load distribution between the girders, pylons, and cables. The determination of pre-tensioning cable stresses is critical in the cable-stayed bridge design procedure. By finding the optimum stresses in cables, the load and moment distribution of the bridge can be improved. In recent years, different research works have studied iterative and modern methods to find optimum stresses of cables. Prestressing is a very powerful technique that consist of introducing a set of stresses into a structure to improve the structural performance during its service life. This technique has allowed the construction of efficient structures, leading to more economical, slender, and durable with longer span bridges.

In this paper, the present work is to model an optimized Cable Stayed Bridge with economized girder with sustainable features. By keeping span to depth ratio as constant parameter an attempt is made here to check the cost effectiveness, structural strength of proposed by bridge with checking a ratio of load carrying capacity to material requirement respectively. The complete work consists an analysis using commercial software(MIDAS CIVIL 2016). The total focus has been given to the static analysis of bridge with variation in deck profiles, i.e., PSC-I Deck, PSC-T beam, PSC-Box girders. For the present work geometry was taken of "Pandit Dindayal Upadhyay Cable Stayed Bridge" which is constructing on Tapi river across Athwa to Adajan.

II. GEOMETRY OF BRIDGE

Total span = 300 m.

Main span = 150 m.

Side span = 75 m. (2 x 75m = 150 m).

Number of pylon : 2 Nos.

Number of lane : 4

Number of cable plane : 1

Number of cable : 24 Nos.

III. STRUCTURAL MODEL CONFIGRUATION

A three dimensional finite element model was ready in MIDAS CIVIL 2016 software, which is a advanced software of design in India for cable stayed bridge analysis. The following table indicates the material properties and sectional properties were used to prepare a model : (see table :1 and 2)

Table No 1 : Material properties

Material Name	Type	Standard	Grade	Elasticity (kN/m^2)	Poisson Ratio	Density (kN/m^3)
PSC 4-cell Box Girder	PSC	IS(PSC)	M 50	2.947e+01	0.17	2.39e+001
PSC 1-cell Box Girder	PSC	IS(PSC)	M 50	2.947e+01	0.17	2.39e+001
PSC Multi-T Girder	PSC	IS(PSC)	M 50	2.947e+01	0.17	2.39e+001
PSC Multi-I Girder	PSC	IS(PSC)	M 50	2.947e+01	0.17	2.39e+001
Pylon	Concrete	IS(RC)	M 50	3.535e+007	0.2	2.50e+001
Pylon-1	Concrete	IS(RC)	M 50	3.535e+007	0.2	2.50e+001
Cable	Steel	IS(S)	Fe 540	2.050e+008	0.3	7.688e+001
Cross beam	Concrete	IS(RC)	M 50	3.535e+007	0.2	2.50e+001

Table No 2 : Sectional properties

Section Name	Section Dimension		Type	Area (m2)	Izz (m4)
	Width (m)	Height (m)			
PSC 4-cell Box Girder	23.50	3	PSC Box	29.47	1078.4
PSC 1-cell Box Girder	23.50	3	PSC Box	39.30	2063
PSC Multi-T Girder	23.50	3	PSC Box	19.9	276.3

PSC Multi-I Girder	23.50	3	PSC Box	18.65	323
Pylon	3(1.5)	4.5(1.5)	Hollow Rectangular	11	9.91
Pylon-1	3	4.5	Solid Rectangular	13.5	10
Cable	0.2		Solid circular	3.14e-02	7.85e-05
Cable	0.22		Solid circular	3.80e-02	1.149e-04
Cable	0.23		Solid circular	4.15e-02	1.373e-04
Cross Beam	0.2	0.3	Solid Rectangular	6.0e-02	2.0e-04

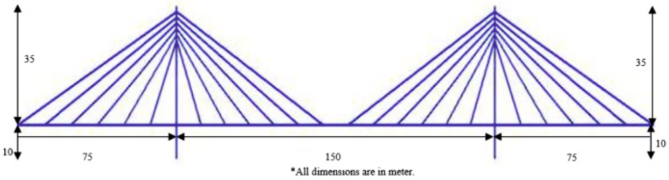

Figure 1 : Elevation layout of "PANDIT DINDAYAL UPADHYAY Cable-stayed Bridge"

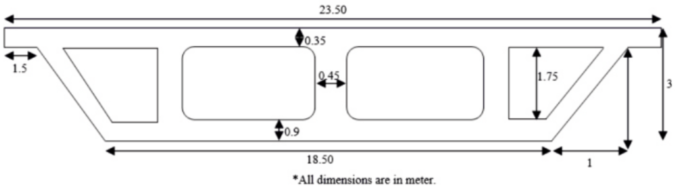

Figure 2 : Dimension of PSC 4-cell box Girder

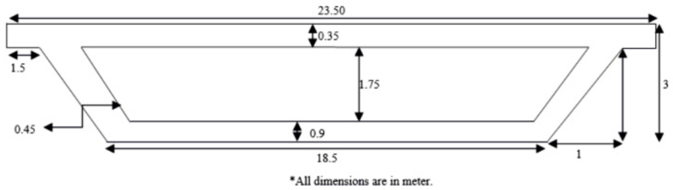

Figure 3 : Dimension of PSC 1-cell box Girder

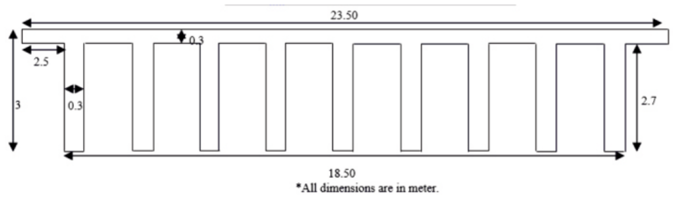

Figure 4 : Dimension of PSC T Girder

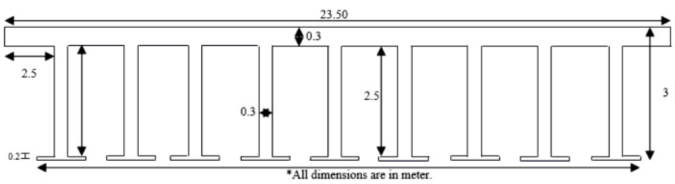

Figure 5 : Dimension of PSC I Girder

The following conditions and assumptions are used in the modeling process :

1. The moving load used as per IRC 6 : 2014 Section : II LOADS AND STRESSES specifications Class AA Loading.
2. The Secondary Dead load is 55.76 kN/m.
3. The Yield Stress of cable is 1860Mpa.
4. The Girder PSC grade is M 50 with design allowable stress is 16.5Mpa.
5. The pylon concrete grade is M50.

The various type of girders are shown in above figures.

The girder depth is 3m for all type of girder and schematic diagram and detailed summary shown in above figures. The pylon shape is single type with cable arrangement system is fan system. The cables are high strength parallel strength with yield stress 1860Mpa.

IV. STATIC ANALYSIS

Static analysis is done by MIDAS CIVIL 2016 Software under load combination of dead load and moving load shown in the figure.

Table No 3 : Load Combination

Load	Value
Dead load	Calculate by software.
Secondary Dead load	55.76 kN/m.
Moving Load	Class A + Class AA loading

- SIDL Calculation(Super Imposed Dead Load) :

SIDL Loads like Barriers, Footpath and kerb is generally taking as 0.5 kN/m^2 u.d.l. with entire Span. Now, Asphalt Density = 2200 kN/m^2

Assume, Wearing Coat = 80 mm

SIDL Load = 22 x 0.08

= 1.76 kN/ m^2

Total SIDL Load = 1.76 + 0.5

= 2.26 kN/m^2

Total Width of Deck = 23.5m

SIDL Load along deck = 23.5 x 2.26

= 53.11 kN/m

Total Factored SIDL = 1.5 x 53.11

= 55.76 kN/m

4.1 STATIC EFFECTS IN BRIDGE COMPLETION STAGE

Figure-6 Shows axial force in girder. The origin of the horizontal axis is the same as the x-axis in figure –1.

I. Girder Axial Force :

For M 50 grade PSC,

Maximum allowable stress,

= 0.33 x f_{ck} IRC-18 : 2000

= 0.33 x 50 Pg. No. : 9

= 16.5 N / mm^2

First, Stress in N / mm^2 converted into kN/m^2 = 16500 kN /m^2 Second, Stress converted into force

$$\text{Girder Stress} = \frac{\textit{Girder Force}}{\textit{Area}}$$

1. 4-cell Box Girder Force = Girder stress x area

= 16500 x 29.47

= 486255 kN

2. 1-cell Box Girder Force = Girder stress x area

= 16500 x 39.30

= 648450

3. Multi-T Girder Force = Girder stress x area

= 16500 x 19.9

= 328350 kN

4. Multi-I Girder Force = Girder stress x area

= 16500 x 18.65

= 307725 kN

1.) 4-cell Box Girder :

At Pylon,

The Girder force = 69278.48 kN

69278.48 < 486255 kN.

=O.K

2.) 1-cell Box Girder :

At near to Pylon in the main span,

The Girder force = 71456.08 kN

71456.08 < 648450 kN.

=O.K

3.) Multi-T Girder :

At near to Pylon in the main span,

The Girder force = 21635.33 kN

21635.33< 328350 kN.

=O.K

4.) Multi-T Girder :

At near to Pylon in the main span,

The Girder force = 20933.7 kN

20933.7 < 307725 kN.

=O.K

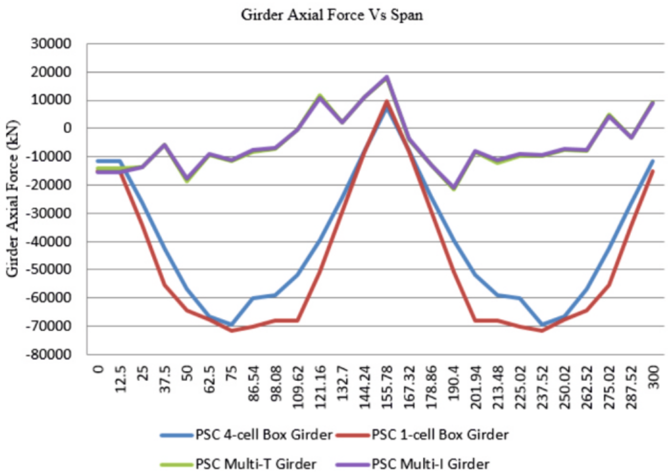

Figure 6 : Axial force of girder under combination effect of dead load + secondary dead load + moving load

Table 4 : Comparison of Girder Force (kN)

Type of Girders	Allowable Girder Force (kN)	Girder Force(kN)	Check
PSC 4-cell Box Girder	486255	69278.48	ok
PSC 1-cell Box Girder	648450	71456.08	ok
PSC Multi-T Girder	328350	21635.33	ok
PSC Multi-I Girder	307725	20933.7	ok

It indicate that the maximum girder axial force is more near to the pylon which is in compression. Table-4 indicates the comparison of girder forces of various type of deck profiles.

II. Girder Stress :

For M-50 grade PSC,

Maximum allowable stress,

$= 0.33 \times F_{ck}$

$= 0.33 \times 50$

$= 16.5\ N/mm^2$ IRC-18 : 2000

1.) 4-cell Box Girder : Pg No. : 9

At Pylon,

2.35 Mpa < 16.5 Mpa = O.K

2.) 1-cell Box Girder :

At Pylon,

2.33Mpa < 16.5 Mpa = O.K

3.) PSC Multi-T Girder :

At mid of the main span,

4.55 Mpa < 16.5 Mpa = O.K

4.) PSC Multi-I Girder :

Near to Pylon,

4.79 Mpa < 16.5 Mpa = O.K

Figure-7 shows that the maximum compressive girder stress at the pylon in 4-cell box girder and 1-cell box girder. In PSC multi-T type girder compressive girder stress occur at mid of the main span. And in PSC multi-I type girder compressive girder stress also occur at mid of the main span. In these four type of deck-profiles, girder axial stress satisfy with allowable compressive stress as per IRC criteria, which are shown in Table-5.

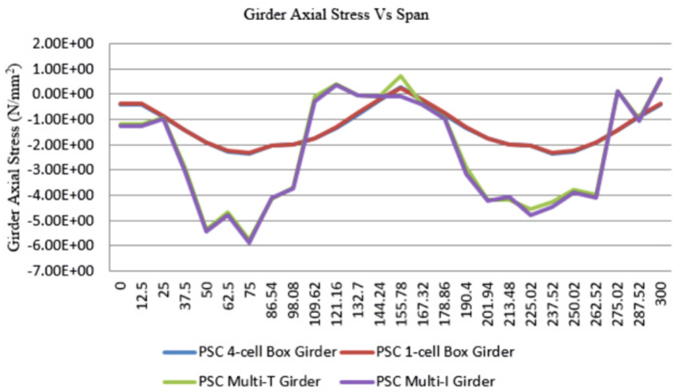

Figure 7 : Axial stress of girder under combination effect of dead load + secondary dead load + moving load

Table 5 : Comparison of Girder Axial Stress (N/mm^2)

Type of Girders	Allowable Girder Stress(N/mm^2)	Girder Stress(N/mm^2)	Check
PSC 4-cell Box Girder	16.5	2.35	ok
PSC 1-cell Box Girder	16.5	2.33	ok
PSC Multi-T Girder	16.5	4.55	ok
PSC Multi-I Girder	16.5	4.79	ok

III. Girder bending Moment :

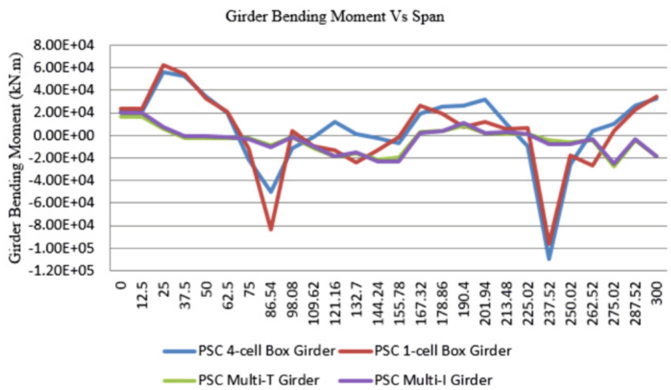

Figure 8 : Girder bending moment under combination effect of dead load + secondary dead load + moving load

Table 6 : Comparison of Girder Bending Moment (kN.m)

Type of Girders	Max. Girder Bending Moment(kN.m)(-)	Min. Girder Bending Moment(kN.m)(-)
PSC 4-cell Box Girder	52500	1500
PSC 1-cell Box Girder	96200	1300
PSC Multi-T Girder	27300	1660
PSC Multi-I Girder	25400	1140

IV. Cable Stress :

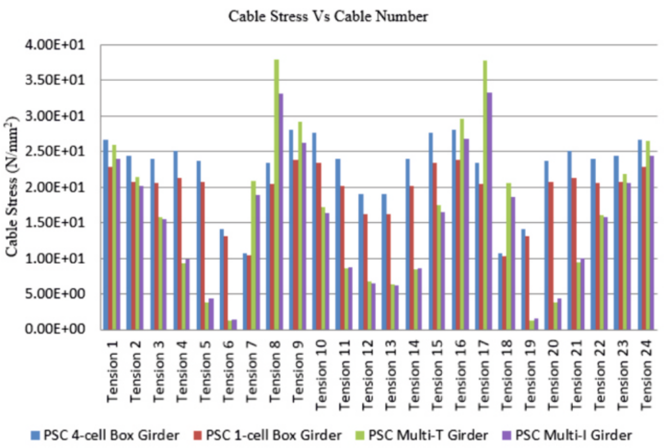

Figure 9 : Cable stress under combination effect of dead load + secondary dead load + moving load(Class A + Class AA)

Table 7 : Comparison of Cable Stress (N/mm^2)

Type of Girders	Allowable Cable Stress(N/mm^2)	Max. Cable Stress(N/mm^2)	Check
PSC 4-cell Box Girder	744	606	ok
PSC 1-cell Box Girder	744	663	ok
PSC Multi-T Girder	744	679	ok
PSC Multi-I Girder	744	681	ok

We are using parellal strand and its yield stress of cable is 1860 N/mm^2.

Under dead load + secondary dead load + Moving load allowable stress is

= 0.4 x Yeild stress of cable.

= 0.4 x 1860

= 744 N/mm^2.

Figure-9 shows the comparision between cable stress of various type of deck profiles. Table 7 indictae the maximum cable stress occur in various deck profiles. It is indicate that the maximum cable stress in PSC multi-I girder compare to remaining deck-profiles. And the minimum stress occur in PSC 4-cell box girder.

4.2 Effects in Operation Stage

Under the combined effect of dead load, secondary dead load and moving load(Class A + Class AA) maximum girder axial force occurs at pylon in 4-cell box girder, near to pylon at side span in 1-cell box girder, and at main span in PSC multi-T type girder or PSC multi-I type girder, which are shown in Table-4. The maximum axial stress under the combined effect of dead load +SIDL+ moving load is occurs at pylon in PSC 4-cell box girder and PSC 1-cell box girder. In PSC multi-T girder and PSC multi-I girder maximum axial stress occurs in the main span. Comparison of girder axial stress describe in Table-5, which are also in the range of allowable axial stress as per IRC criteria. In PSC 4-cell box girder and in PSC 1-cell box girder the maximum bending moment under combination of dead load + secondary dead load + moving load occurs near to pylon in side span. In PSC multi-T girder and in PSC multi-I girder the maximum bending moment occur near the abutment.

Under the combined effect of dead load and moving load the Maximum compressive stress of pylon is 9.19Mpa, 8.50Mpa, 9.73Mpa, and 9.42Mpa in PSC 4-cell box girder, PSC 1-cell box girder, PSC multi-T girder, PSC multi-I girder respectively.

Under the combined effect of dead load and moving load the maximum stress of cable is 606Mpa, 663Mpa, 679Mpa, 681Mpa of PSC 4-cell box girder, PSC 1-cell box girder, PSC multi-T girder, PSC multi-I girder respectively, which are smaller than the allowable stress of cable 744MPa.

V. Conclusion :

By keeping span to depth ratio constant for the analysis of various deck profiles under the load combination stress, force and bending moment are within the permissible limits as per IRC based codal criteria.

By keeping constant span to depth ratio cable diameter is changing significantly, but pylon dimensions are same.

By performance based analysis in the term of cable stress and girder stress, PSC multi-cell box girder is giving better performance.

In the terms of girder bending moment result of PSC multi-I girder and PSC multi-T girder are giving better performance under combination of dead load, secondary dead load and moving load respectively.

According to overall performance based analysis, PSC multi-cell box girder for four lane road in cable-stayed bridge system is proposed.

VI. Future Work :

Further research is needed in the following aspect of crossing cable stayed bridge.

1. Non-linear effects
2. Performance under wind
3. Earthquake loading

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